

Guide 116

Environmental Aspects of Large-Scale Combined Heat and Power



Energy Efficiency Office
DEPARTMENT OF THE ENVIRONMENT

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ENVIRONMENTAL ASPECTS OF LARGE-SCALE COMBINED HEAT AND POWER

This booklet is No. 116 in the Good Practice Guide Series. It is applicable to industrial sites, large hospitals, airports, universities and large community heat systems considering the introduction of combined heat and power (CHP) plant. It outlines the environmental benefits of large-scale CHP and the environmental issues that must be considered in the design, installation and operation of CHP plants. It also recommends some good practices that will help a CHP installation comply with pollution regulations and maximise its environmental benefits. In particular, the Guide discusses the Environmental Protection Act and the requirements for CHP plant. CHP prime movers and boilers can be designed and operated to meet emissions limits using proven techniques without excessive capital and operating costs.

The environmental aspects of small-scale CHP are outlined in a complementary Good Practice Guide, No. 115, 'An Environmental Guide to Small-scale Combined Heat and Power'.

Prepared for the Energy Efficiency Office by:

ETSU
Harwell
Oxfordshire
OX11 0RA

and

Power Engineering Limited
65 Northgate
Newark
Notts NG24 1HD

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1. GUIDANCE NOTES FOR THE IMPLEMENTATION OF SMALL-SCALE PACKAGED COMBINED HEAT AND POWER
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Copies of these guides may be obtained from:

Energy Efficiency Enquiries Bureau
ETSU
Harwell
Oxfordshire
OX11 0RA

Tel No: 0235 436747. Fax No: 0235 432923. Telex No: 83135

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FOREWORD

This guide is part of a series produced by the Energy Efficiency Office under the Best Practice programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

- *energy consumption guides*: (blue) energy consumption data to enable users to establish their relative energy efficiency performance;
- *good practice guides and case studies*: (red) independent information on proven energy saving measures and techniques and what they are achieving;
- *new practice projects*: (green) independent monitoring of new energy efficiency measures which do not yet enjoy a wide market;
- *future practice R&D support*: (purple) help to develop tomorrow's energy efficiency good practice measures.

If you would like any further information on this document, or on the Best Practice programme, please get in touch with your Regional Energy Efficiency Office. Their addresses are given below:

ENGLAND

Energy Efficiency Office (East Midlands Region)

Cranbrook House
Cranbrook Street
Nottingham
NG1 1EY
Tel: 0602 352292

Energy Efficiency Office (North East Region)

Government Office for the
North East
Wellbar House
Gallowgate
Newcastle-upon-Tyne
NE1 4TD
Tel: 091 201 3343

Environmental Issues Unit (North West Region)

Government Office - North West
Sunley Tower
Piccadilly Plaza
Manchester
M1 4BE
Tel: 061 838 5335

Energy Efficiency Office (South Eastern Region)

Charles House
Room 565
375 Kensington High Street
London
W14 8QH
Tel: 071 605 9160

Energy Efficiency Office (Eastern Region)

Heron House
49-53 Goldington Road
Bedford
MK40 3LL
Tel: 0234 276194

Energy Efficiency Office (South West)

Room 309
Government Office for the
South West
Tollgate House
Houlton Street
Bristol BS2 9DJ
Tel: 0272 878665

Energy Efficiency Office (West Midlands Region)

Room 603
Five Ways Tower
Frederick Road
Birmingham
B15 1SJ
Tel: 021 626 2222

Energy Efficiency Office (Yorkshire/Humberside Region)

Dept of the Environment
City House
New Station Street
Leeds
LS1 4JD
Tel: 0532 836376

Energy Efficiency Office (NORTHERN IRELAND)

Dept of Economic Development
Netherleigh
Massey Avenue
Belfast
BT4 2JP
Tel: 0232 529358

Energy Efficiency Office (SCOTLAND)

Scottish Office Industry Dept
Energy Division R6/47
New St Andrew's House
Edinburgh
EH1 3TG
Tel: 031 244 4665

Energy Efficiency Office (WALES)

Welsh Office
Industry Department
Cathays Park
Cardiff
CF1 3NQ
Tel: 0222 823126

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ENVIRONMENTAL ASPECTS OF LARGE-SCALE COMBINED HEAT AND POWER

1. INTRODUCTION

The economy of a developed country relies on a supply of heat and power. Most heat users have fossil fuel combustion equipment installed close to the point of use to supply heat. In contrast, electricity is supplied over a distribution network from central power stations via cables.

The costs of heat and power supplies are governed by the market price of fossil fuels and the efficiency of converting the fuel into usable energy. The thermal efficiency of raising heat from fuel, using appropriate boiler plant, is typically 75% to 80%. Electricity generated from fossil fuels at remote power stations is supplied to its point of use with an average efficiency of around 30%.

1.1 Combined Heat and Power Systems

Combined heat and power (CHP) systems generate electricity and usable heat from the same plant. Their installation has proved economically worthwhile where a single site or group of users, have sufficiently high simultaneous heat and power requirements. CHP is a proven technique with a high level of energy efficiency and environmental benefits. Overall efficiency of energy supply can be raised to 80% or above. CHP can also provide increased security of electrical supply to sites where the risk of failure is unacceptable.

There are now more than 150 large-scale (over 1 MW) CHP plants installed in industrial sites in the UK and over 750 small-scale CHP installations. These have a total installed capacity of around 3,000 MWe of electrical power. In 1993/94, CHP generation was more than 14,000 GWh, approximately 5% of the total electrical power generation in the UK.

CHP installations can be classified into three broad categories; the category selected for a particular site usually depends on the ratio of heat to power required by the site;

- Gas turbine(s) generating electrical power, with exhaust passed into heat recovery boiler(s). These plants normally operate on gaseous fuels but many plants have additional capability to operate on gas-oil as the stand-by fuel.
- Steam cycle CHP incorporating boiler plant raising high pressure steam for electrical generation in a steam turbine. Boilers can be designed to use any available fuel and many can use more than one fuel.
- Reciprocating engine(s) generating electrical power where heat is recovered from both exhaust and engine cooling system. Compression-ignition (CI) engines can operate on a range of gaseous and liquid fuels; spark-ignition (SI) gas engines use methane-based gaseous fuels.

Some installations combine the use of steam turbines with gas turbines (or occasionally reciprocating engines) to create combined cycle CHP installations.

1.2 Good Practice in CHP

Operating a CHP plant is an efficient and secure way of meeting energy demands. The Government has set a target to increase installed CHP capacity in the UK to 5,000 MWe by the year 2000. This will double the current installed CHP capacity. The Energy Efficiency Office is supporting this objective through the Best Practice programme. A number of Good Practice Guides have been published, which evaluate the feasibility, engineering design and operation of a range of CHP options. In particular, Good Practice Guide No 43 gives a detailed introduction to large-scale CHP. A number of CHP installations have been examined in detail and the findings published as Case Studies and Profiles issued as part of

the Best Practice programme. For a complete list of CHP publications available from the Energy Efficiency Office, contact the Energy Efficiency Enquiries Bureau at ETSU (see Appendix 3).

This guide explains the environmental considerations of CHP installations and discusses important environmental aspects and is intended to help owners, designers and operators of existing and future CHP plants achieve the full environmental benefits of CHP. The guide looks at the technical aspects of installing, designing and operating a CHP plant with emphasis on two areas which provide environmental benefits:

- The installation of a CHP plant in an existing industrial site requires careful planning and engineering design to minimise the environmental impact on the local area.
- The design and operation of a CHP installation is subject to a range of legislative requirements which aim to control emissions of pollutants into the environment.

This guide is relevant to CHP installations with an electrical output of at least 1 MW. Good Practice Guide No 115 discusses similar topics for small-scale gas engine CHP installations.

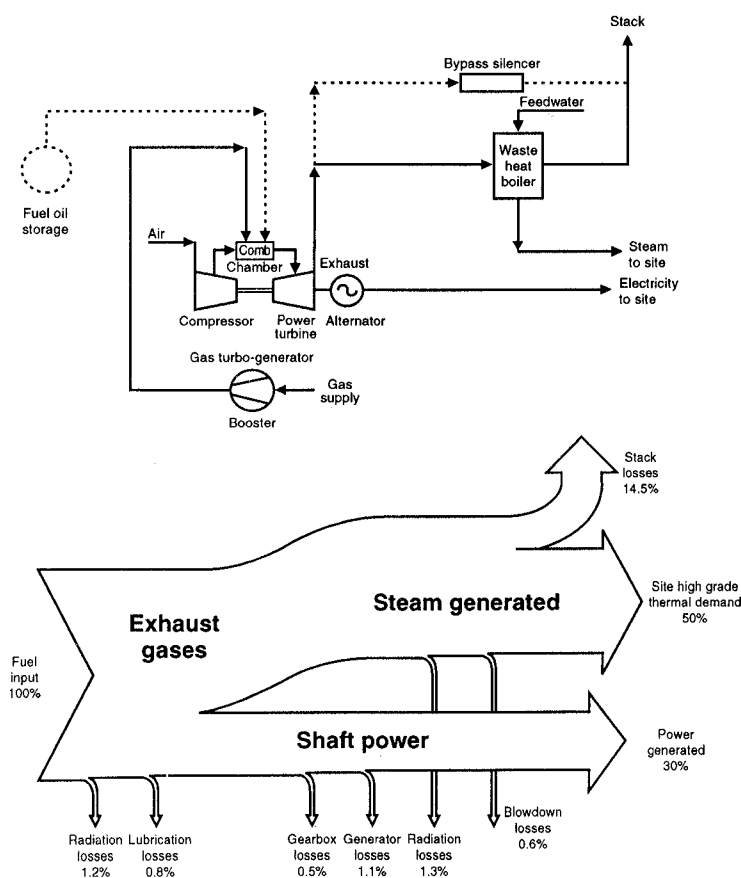


Fig 1 Schematic of typical turbine CHP and its energy balance

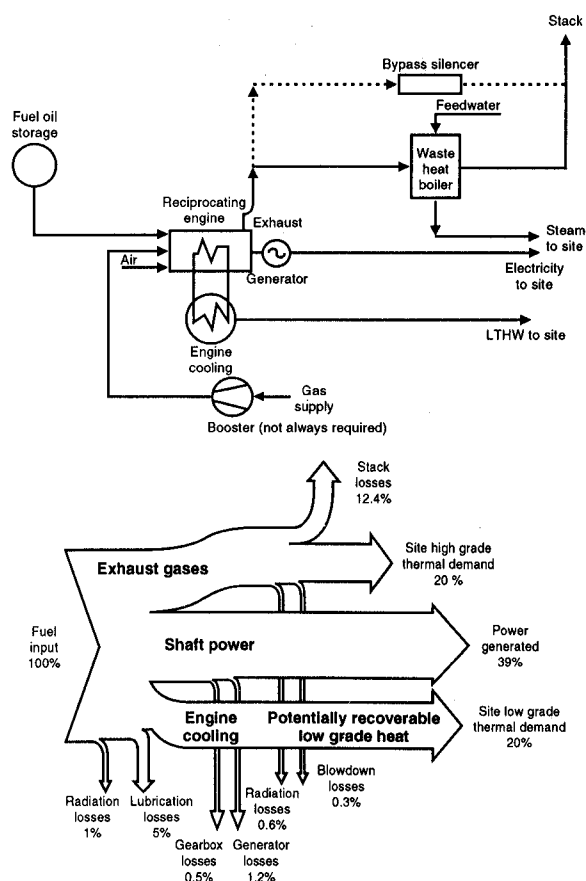


Fig 2 Schematic of dual-fuel compression-ignition engine CHP and its energy balance

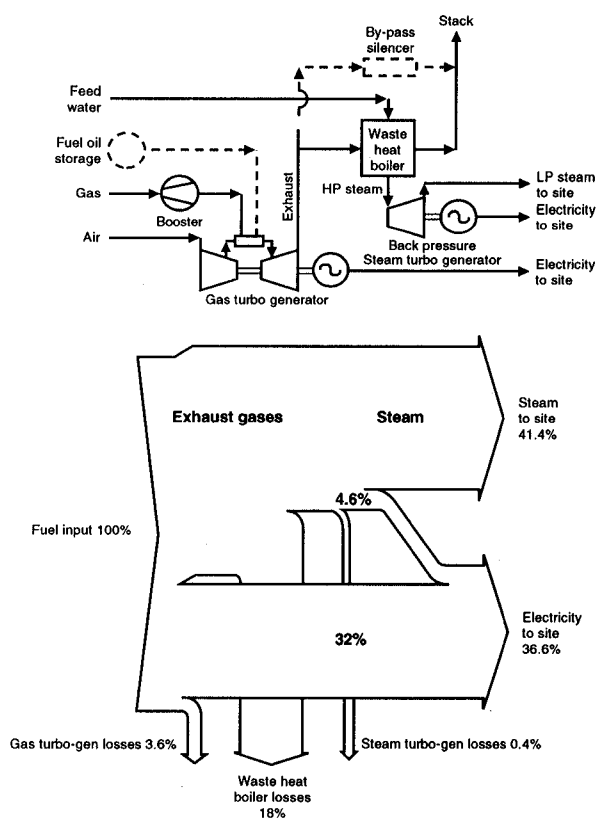


Fig 3 Schematic of combined cycle CHP and its energy balance

2. CHP AND ATMOSPHERIC EMISSIONS

CHP is a highly efficient energy process with a significant reduction in combustion products per unit of energy used compared with traditional heat and power generation systems. Reducing the amount of combustion products has a beneficial effect on air pollution and its consequences. Adopting CHP usually slightly increases the fuel consumption on site but displaces significantly greater amounts of fuel used at (and emissions generated by) the central power generating stations by reducing the electricity purchased.

This section of the guide explains how combustion processes produce polluting emissions and quantifies the emissions savings CHP can achieve. A procedure has been developed to calculate the reduction in emissions when any combination of CHP plant replaces boiler plant and purchased electricity.

2.1 Combustion of Fossil Fuels

Fossil fuel combustion is a reaction between oxygen and the constituents of the fuel. The combustion process gives off heat and this is usually a required and beneficial product of the process. However, fossil fuel combustion discharges gases into the atmosphere which have damaging effects on the earth's environment.

All fossil fuels contain carbon which is the main combustible constituent; hydrogen is the other significant energy source. The combustion of carbon and hydrogen produces large amounts of carbon dioxide and water vapour in the exhaust products. Combustion processes also produce other gaseous pollutants depending on the composition of the fuel and the type of combustion process.

A table of atomic and molecular weights, used in the following topics of combustion chemistry, is given in Appendix 1.

2.1.1 Carbon Dioxide (CO₂)

This is the gas produced in the greatest quantity by combustion processes. The aim of any combustion process is to convert all the available carbon to CO₂ to release the maximum available energy. Burning carboniferous fuel combines atmospheric oxygen (O₂) with carbon, to produce CO₂.

Table 1 Carbon fuel heat and CO₂ emissions

Fuel	Typical % carbon in fuel	Tonnes of CO ₂ produced/tonne of fuel	kg of CO ₂ /GJ of 'available' energy (GCV)	kg/MWh (thermal input)
Coal	87	3.2	91	262
Heavy fuel oil	86	3.1	74	213
Gas-oil	86	3.1	69	199
Natural gas	73	2.8	50	144

CO₂ is an inert gas present in the atmosphere as part of the natural carbon cycle of the earth. However, increasing CO₂ level is a major cause of the 'greenhouse effect', increased risk of global warming and climatic change. The historical increase in CO₂ is shown in Fig 4 and it has been calculated, assuming world-wide growth trends continue, that carbon combustion will not significantly reduce.

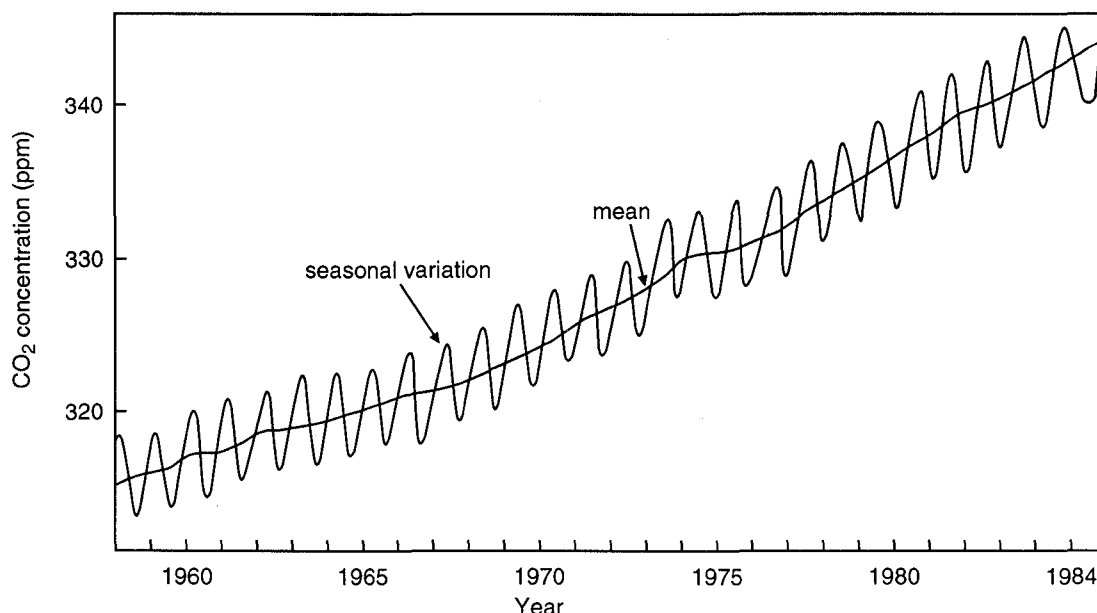


Fig 4 Historical increase in CO₂ levels

Source: Bacastow & Keeling, Carbon Cycle Modelling, Wiley, 1981

The amount of CO₂ produced depends on the carbon content of a fuel and the rate at which fuel is used. Only by burning less carbon can CO₂ output be reduced. Any technique with greater efficiency in using fuel to release energy reduces the level of emissions.

2.1.2 Sulphur Dioxide (SO₂)

Sulphur dioxide is produced from the combustion of sulphur in the fuel. One kilogramme of sulphur in a fuel results in two kilogrammes of SO₂ in the exhaust. Further complex chemical reactions in the atmosphere result in the production of acidic compounds such as sulphuric acid (H₂SO₄). These are a major cause of 'acid rain' and its effects on the ecology of the earth's surface. Typical fuel sulphur contents and the SO₂ emissions are as follows:

Table 2 Sulphur content in fuels and typical SO₂ emissions

Fuel	Typical % sulphur in fuel	kg of SO ₂ produced/tonne of fuel	kg of SO ₂ /GJ of available energy (GCV)	kg/MWh (thermal input)
Coal *	2.0	40	1.15	3.31
Heavy fuel oil	2.5	50	1.17	3.37
Gas-oil	0.3	6	0.13	0.17
Natural gas	nil	nil	nil	nil

* Dry ash free basis where typically 20% by mass is non-combustible.

The most effective way to reduce SO₂ emissions is to reduce the amount of sulphur burned in combustion processes. Pollution abatement techniques are available and a proven process known as flue gas de-sulphurisation (FGD), can extract SO₂ from combustion process exhaust. Further details of this are given in Section 5.2.2.

2.1.3 Carbon Monoxide (CO)

Carbon monoxide is produced by incomplete combustion of carbon; this is caused by a number of different factors in a combustion process. The rate of production is usually small, typically in parts per million of exhaust gases, but CO production is significantly increased

when combustion is poorly controlled. CO is a toxic gas and in large quantities contributes to local smog problems and respiratory problems.

CO production can usually be limited by maintaining and controlling combustion equipment.

2.1.4 Oxides of Nitrogen (known collectively as NO_x)

NO_x is formed by the high temperature reaction of oxygen (O_2) with nitrogen (N_2) to produce nitric oxide (NO) and nitrogen dioxide (NO_2). The production of NO_x is not only dependent on the fuel used, unlike the production of CO_2 and SO_2 . The rate of formation of NO_x is affected by a number of factors within the combustion process including combustion temperature, residence time in the combustion zone, and the concentrations of oxygen and nitrogen present. NO_x production is classified in two ways:

- Thermal NO_x is formed by a reaction between oxygen and atmospheric nitrogen and occurs to a greater or lesser extent in all combustion processes.
- Fuel NO_x is formed by a reaction involving the nitrogen in the fuel. This source of NO_x is, therefore, limited to the combustion of oils and solid fuels that contain chemically-bound nitrogen.

NO_x produced in a combustion process typically consists of more than 90% NO and less than 10% NO_2 . However, during atmospheric cooling some of the NO reacts with ozone (O_3) and forms NO_2 . This contributes to the ozone layer depletion in the upper atmosphere and smog formation at ground level. NO_2 is also considered harmful to the respiratory system. Atmospheric reactions incorporating NO also lead to formation of nitric acid (HNO_3) which contributes to acid rain.

2.1.5 Particulates

Any combustion process using solid or liquid fuels can produce solid particles if incorrectly designed or operated. These particles are usually visible in the form of colouration or 'smoke' in the exhaust. The common cause of this problem is the presence of unburned carbon particles or inert materials such as ash, in the exhaust.

Most particulates ultimately settle on surfaces around the point of discharge and only cause environmental damage if they are toxic, corrosive, or if produced in large quantities. While airborne, particulates present a hazard to animal respiratory systems and the sight of airborne smoke is frequently regarded as an intrusion on the local environment. The degree of visible particulates in an exhaust is often a warning sign that the combustion process is not controlled correctly.

2.1.6 Other Compounds

Combustion processes can produce small quantities of various organic and chemical compounds which may include gases of unburnt hydrocarbons (UHC). In general, the presence of these compounds often occur with emissions of particulates and carbon monoxide associated with poorly controlled combustion. In particular, inadequate maintenance, or poor control of equipment, can lead to increased emissions of unburned fuel and organic compounds. Under normal circumstances emissions levels of these compounds are not considered a major concern.

2.2 Emissions from Industrial and Commercial Boilers

Most of the heat required by industrial sites and commercial premises comes from steam or hot water raised in boilers burning carbon-based fuel, usually natural gas, oil, or coal. Most boiler installations aim to be energy efficient and minimise visible levels of particulates in the exhaust. However, most boiler design and operation does not include any provisions to

limit emissions of SO₂, NO_x and CO and relies on maintenance and adjustment of the burner equipment to keep emissions to a minimum.

In general, CO and NO_x emissions levels depend on the combustion characteristics of the burner and the fuel used. CO₂ and SO₂ emissions depend totally on the carbon and sulphur contents of the fuel respectively.

Table 3 Emissions from fuels

Fuel	NO_x (kg/tonne of fuel)	CO (kg/tonne of fuel)
Coal	4.0 - 10.5 (6.1)	0.1 - 18.0 (5.2)
Heavy fuel oil	3.5 - 10.0 (7.5)	0.0 - 11.7 (0.5)
Gas-oil	1.8 - 4.3 (2.6)	0.0 - 1.2 (0.2)
Natural gas	1.4 - 4.6 (2.6)	0.0 - 0.2 (0.1)

Table 3 shows typical levels of emissions calculated from a survey of industrial boilers in the UK during the 1980's. The survey data are in kilogrammes of emissions per tonne of fuel used showing the upper and lower ranges for each category, with the average shown in brackets.

The data clearly show the expected trend of higher NO_x emissions from coal and heavy fuel oil which have higher nitrogen contents and usually burn at higher temperatures. The data ranges relate to the varying types of combustion equipment used in the boilers and the variation in equipment maintenance and control. In particular, the wide range of CO emissions levels is caused by the variation in adjustments of air/fuel ratio in the boilers.

Table 4 takes the average NO_x emissions level for each data group, and summarises the emissions in grammes per kWh of boiler heat output, based on typical fuel compositions and boiler efficiency of 80%; comparable figures for CO₂ and SO₂ emissions are derived from the data shown in earlier sections of this guide. The table shows the general trend of highest levels of emissions from coal and HFO, reducing progressively as lighter oil and gas fuels are used.

Table 4 Typical emissions from industrial boilers

	Coal-fired boilers	HFO-fired boilers	Gas-oil-fired boilers	Gas-fired boilers
NO _x g/kWh	0.78	0.79	0.26	0.22
CO ₂ g/kWh	410	333	313	226
SO ₂ g/kWh	5.14 2.0% sulphur in fuel	5.27 2.5% sulphur in fuel	0.59 0.3% sulphur in fuel	0.00 No sulphur in fuel

Note: Data based on boiler efficiency of 80% (Gross CV).

SO₂ emissions from all boilers increase/decrease in proportion to sulphur content of fuel.

2.3 Emissions from Centralised Electricity Generation

The 1993 Digest of UK Energy Statistics shows that around 80% of electricity consumed in the UK is produced by burning fossil fuel in central power stations. The remainder is produced by generation in nuclear stations, on-site generation (mainly CHP), renewable sources such as hydro-electric, wind power and biofuel combustion, or imported from Europe.

The majority of fossil fuel consumed is pulverised coal which is burned in boilers to raise high pressure steam for steam turbines generating electricity. Coal-fired power stations typically have an efficiency of approximately 35%; the rest of the energy is lost as heat rejected into the environment. Transmission and distribution losses reduce the overall efficiency of electricity supply to around 30% at its point of use. A significant proportion of coal-fired plant has been fitted with low- NO_x burners and the older coal-fired stations will progressively be closed down as more efficient plant comes on stream. Some oil-fired generating stations are still used for limited stand-by and peak-opping duties.

Gas-fired power stations are increasingly being used with gas turbines generating power and additional electricity generated from steam raised by recovering the heat from the gas turbine exhaust; this is known as combined cycle gas turbine (CCGT) generation. Supply efficiency is typically around 45% with the rest of the energy rejected into the environment. The large gas-fired turbines achieve low NO_x levels (typically around 50 mg/Nm^3) using the latest technology combustion systems.

Gas-fired power generation will not completely replace coal systems and a significant proportion of UK electricity will continue to be generated in coal-fired power stations. However, the older coal-fired stations are least efficient and produce the highest levels of emissions per unit of power provided. It is likely, therefore, that this will be the form of generation replaced by new CHP installations during the next few years. Supply efficiency for CHP is typically 80%.

The emissions from fossil fuel power stations vary according to the type of installation and the fuel used. Typical emissions from electricity generation are summarised in Appendix 5. The data clearly show that gas-fired CCGT stations have the lowest emissions. The 'UK Supply Average From All Sources' includes power from CHP, nuclear sources and renewable energy sources.

2.4 Emissions from CHP Systems

As in all combustion processes, the CO_2 and SO_2 produced by CHP prime movers depends on the carbon and sulphur content of the fuel. Other emissions vary according to the design characteristics of the individual machinery. Emissions from steam cycle CHP only come from the boiler in which the steam is raised and are not affected by using steam to generate electricity. Further details of prime movers and heat recovery boilers can be found in Energy Efficiency Office (EEO) Good Practice Guide 43.

2.4.1 Gas Turbines

The combustion process in a gas turbine occurs with high levels of excess air since the power output obtained relates to the mass flow rate achieved through the turbine. Production of CO and UHC is very low under normal conditions. NO_x emissions from gas turbines are not high and can be reduced by using water/steam injection or low- NO_x burners. Typical emissions from gas turbines are shown in Table 5, expressed in grammes per kWh of power generated.

The NO_x emissions are based on turbines complying with the current limits of 60 ppm on gas-firing and 80 ppm on oil-firing (see Tables 13 and 14 in section 4.3).

Table 5 Emissions from gas turbines

	NO_x g/kWh	CO₂ g/kWh	SO₂ g/kWh
Firing on natural gas	1.1	610	nil
Firing on gas-oil	1.6	800	1.4

Gas turbines for CHP can also use other gaseous fuels. Methane-based fuel gases from landfill sites, sewage treatment works and mine ventilation contain high levels of inert constituents such as nitrogen and CO₂. Using these fuels produces over 50% less NO_x emissions than natural gas due to the lower combustion temperature. Refinery gases have a high hydrogen content and their use results in up to 2.5 times more NO_x emissions, although the lower carbon content of the fuel results in lower CO₂ emissions. Using these fuels in prime movers reduces emissions by replacing fuel burned in other combustion processes and gives significant environmental benefits when compared with venting to atmosphere or flaring-off these 'waste' gases.

2.4.2 Compression-ignition (CI) Engines

Compression-ignition engines generally operate with lower air to fuel ratios and higher combustion temperatures than gas turbines in order to maximise efficiency; this results in relatively high levels of NO_x emissions per unit of power. The actual NO_x emissions vary widely between different engine designs; in some cases it is possible to reduce NO_x emissions by operating at lower engine efficiency, with a small increase in CO₂ emissions. CI engines can operate on gas fuels if a small quantity of 'pilot oil' is injected to ignite the gas. This fuel option gives lower NO_x emissions than oil fuels but usually reduces the power output from the engine. Emissions from compression ignition engines in grammes per kWh of electrical output are shown in Table 6.

Table 6 Emissions from compression-ignition engines

	NO_x g/kWh	CO₂ g/kWh	SO₂ g/kWh
Firing on natural gas (with pilot oil)	5 - 10	500 - 600	0.1
Firing on heavy fuel oil	8 - 15	700 - 800	10.8

2.4.3 Spark-ignition Gas Engines

Spark-ignition gas engines are not normally used in large-scale industrial CHP due to the limit of available engine sizes, and the low grade of heat available from the engine. Typical emissions from gas engine CHP are given in Table 7. Information on gas engine emissions in CHP is given in the complementary Good Practice Guide No. 115, 'An Environmental Guide to Small-Scale Combined Heat and Power'.

Table 7 Emissions from spark-ignition gas engines

	CO₂ g/kWh	NO_x g/kWh	CO g/kWh	SO₂ g/kWh
Firing on natural gas	580	15 - 25	1 - 2	Negligible

2.4.4 Waste Heat Boilers

The waste heat boiler in a CHP installation is where heat is recovered from the prime mover exhaust and used to raise steam or hot water. Heat recovery has no effect on the content of the prime mover exhaust gases although it can result in acid condensation if temperatures fall too low.

For additional boiler output a waste heat boiler can incorporate supplementary firing, using prime mover exhaust instead of ambient air. This technique is explained in Good Practice Guide No 43. Raising heat by supplementary firing is more energy efficient than using conventional boilers and CO₂ emissions are about 10% less than emissions from conventional boilers as shown in Table 4.

In supplementary firing, exhaust gases contain less oxygen than ambient air and this means that less NO_x is produced than by conventional boilers. NO_x output from supplementary firing can typically be about half of that produced by conventional boilers (see Table 4). Recent tests showed that under certain firing conditions, no additional NO_x is produced by supplementary firing. Replacing conventional boilers by supplementary firing of a waste heat boiler, therefore increases the environmental benefits of a CHP installation.

2.5 Emissions Savings Achieved by CHP

A well-designed and operated CHP plant will always improve energy efficiency and significantly reduce CO₂ emissions. Since CHP is almost always replacing electrical power from the older coal-fired power stations, significant reductions of SO₂ and NO_x emissions are also achieved because of the lower sulphur content fuel and more modern combustion equipment.

Table 8 shows a summary of typical emissions from a range of CHP installations based on emissions from the prime movers and boilers. The table also shows the typical heat to power ratio for each scheme. From Tables 8 and 9 the emissions savings can be calculated for a range of CHP options.

Table 8 Typical emissions from combined heat and power systems

CHP system type	A	B	C	D	E	F	G	H
	Gas turbine with waste heat boiler	Gas turbine with waste heat boiler and back-pressure steam turbine	Boiler and back-pressure steam turbine	Boiler and back-pressure steam turbine	Boiler and back-pressure steam turbine	CI engine with waste heat boiler	CI engine with waste heat boiler	Lean-burn SI engine with waste heat boiler
Fuel type	natural gas	natural gas	natural gas	HFO	coal	natural gas	HFO	natural gas
Emissions in g/kWh of electrical power produced								
CO ₂	610	510	1,510	2,220	2,700	570	800	500
NO _x	1.1	0.9	1.5	5.3	5.2	5 - 10	8 - 15	3
SO ₂	nil	nil	nil	35.2 (2.5% sulphur in fuel)	34.3 (2.0% sulphur in fuel)	nil	10.5 (2.5% sulphur in fuel)	nil
Ratio of recovered heat to power generated	1.6	1.1	5.5	5.5	5.5	1.4	1.4	1.6

Note: NO_x emissions/kWh from gas turbines increase/decrease in proportion to the turbine emissions rate expressed in parts/million (ppm). Datum used is 60 ppm for natural gas firing.

SO₂ emissions from all plant increase/decrease in proportion to sulphur content of fuel

Table 9 shows a worked example of the procedure for this assessment and Table 10 summarises the results from a range of typical CHP options (all options displace coal-fired central power generation).

Table 9 Example of a calculation of emissions savings achieved by CHP

	Ref	CO ₂ g/kWh	NO _x g/kWh	SO ₂ g/kWh
From Table 4, enter data from one column for the type of boiler being replaced by CHP (Example: HFO fired from Table 8)	(V)	333	0.79	5.27
Data for coal-fired central power generation (alternative data are illustrated in Appendix 5)	(W)	990	2.7	15.0
From Table 8, enter data from one column for the type of CHP system selected (Example: Type D, HFO boiler with back-pressure steam turbine)	(X)	2,220	5.3	35.2
From the same column of Table 8, enter ratio of recovered heat to power generated (Example: Type D, HFO boiler with back-pressure steam turbine)	(Y)	5.5	5.5	5.5
Multiply (Y) by (V)	(Z)	1832	4.3	29.0
Calculate the emissions saved in g/kWh of power generated (W) + (Z) - (X)		602	1.7	9.0

Table 10 Summary of emissions savings results from a range of CHP options (g/kWh)

	CO ₂	NO _x	SO ₂
Type A replacing coal boilers	1036	2.9	23.2
Type A replacing HFO boilers	913	2.9	23.4
Type D replacing HFO boilers	602	1.7	9.0
Type E replacing coal boilers	545	1.8	9.0
Type F replacing gas boilers	736	(4.5)	15.0
Type H replacing HFO boilers	1023	1.0	23.4

Case History 1

The SmithKline Beecham site at Worthing is a pharmaceutical processing and production plant. It operates continuously for more than 8,000 hours/year. The site has energy demand levels of around 10 MW of electricity and an average of 20 tonnes/hour of steam. These energy demands are expected to increase in the coming years.

A 13 MW gas turbine CHP plant has been installed to supply electricity and steam to the site alongside the existing gas-fired boilers which will back up the CHP plant. The CHP plant will reduce annual CO₂ emissions by approximately 55%, NO_x by approximately 60% and will almost eliminate emissions of SO₂.

Case History 2

The Federal Tait paper mill at Inverurie near Aberdeen operates for about 8,500 hours/year. It uses approximately 70 tonnes/hour of steam and 15 MW of electrical power. Prior to installing CHP the site used coal, natural gas or heavy fuel oil in its boilers to provide steam for the site. Some electrical power was also generated.

A new combined cycle CHP plant has increased the efficiency and the security of the energy supply to the site and has replaced the use of oil and coal for steam and electricity production. The CHP plant at Tait Paper has reduced the level of CO₂ emissions by around 180,000 tonnes/year, NO_x by 200 tonnes/year and SO₂ by 2,000 tonnes/year.

2.6 Operation and Maintenance Requirements

A programme of plant inspection and maintenance should be implemented to continue to achieve the environmental benefits and energy efficiency of CHP. High levels of prime mover availability and performance are key to achieving reductions in energy costs and emissions. Monitoring systems can track performance and the condition of a CHP installation to help diagnose problems early, minimising downtime and repair costs.

Most gas turbine and engine suppliers can provide services to carry out planned and unplanned maintenance and use of these specialised services will usually ensure the CHP scheme provides optimum benefits.

Gas turbines and reciprocating engines need to be shut down periodically for inspections and major overhauls by specialist maintenance engineers. Typical maintenance requirements for prime movers are detailed in Good Practice Guide No 43. Other maintenance checks should be carried out every few days or more often, by operators or site maintenance staff. Although some CHP plants are run unattended, they require regular inspections to prevent maintenance requirements having a major effect on plant reliability.

3. ENVIRONMENTAL CONSIDERATIONS OF CHP INSTALLATIONS

Installing a CHP system usually increases the heat and power plant on a site. The effects on the local environment of expanding a site need to be addressed at an early stage in the project, as part of the planning and evaluation.

The size and type of the installation will affect whether consent is required for any expansion under the Town and Country Planning Acts. An early approach to the planning department of the appropriate local authority will help to clarify any requirements. A planning application may need to be supported by a study of the effects of the development on the local environment.

The initial evaluation of the viability and acceptability of the project needs to consider a range of environmental aspects to help minimise their impact on the surrounding area. Some projects may need a detailed environmental impact assessment for the planning and consultation procedure.

3.1 Dispersal of Combustion Products

Combustion products from a CHP plant do not represent any form of toxic hazard to the local environment. However, it is important that they achieve adequate dilution in the atmosphere. The Air Quality Standards Regulations 1989 define concentration limits for some of the substances in the ambient air.

Adequate dispersion can be achieved by ensuring that atmospheric discharge occurs at sufficient height above the surrounding area. The required chimney height can be determined from a wide range of factors including the exhaust contents, the background air quality, the topography of the local area, and the temperature and velocity of the exhaust. However, erecting a new chimney has a visual impact on the surrounding area. The chimney height can be minimised by using the cleanest practicable combustion technology and low sulphur fuel. Re-using existing chimneys can be helpful where possible.

3.2 Noise

All CHP systems have a prime mover which emits noise into the adjacent area and the exhaust stream. Most CHP systems also have a range of auxiliary equipment which generate noise either continually or intermittently. For comparison, Table 11 shows typical noise levels close to a range of sources.

Table 11 Typical noise levels of a range of sources and locations

Source	Typical noise level dB(A)
Public library	35 - 40
Business premises/offices	55 - 65
Passing vehicle	75 - 90
Pneumatic road-breaking drill	95 - 110
A jet aircraft on take-off	110 - 125
CHP Plant with normal acoustic equipment (see Sections 3.2.1 & 3.2.2 for more information)	Around 80

In practice all noise sources emit sounds over a range of audible frequencies. The 'A' scale of measurement simulates the sensitivity of the human ear to different frequencies.

Although the human ear is less sensitive to sound below 1,000 Hz, noise at lower frequency is attenuated less by acoustic shielding. It is, therefore, important that consideration is given to both the characteristics of noise sources and the effect of acoustic insulation on sound reduction over the full frequency range detected by the human ear.

Intermittent noise and noise sources that emit discrete tones can cause a nuisance. CHP installations usually operate continually but care must also be taken to shield sources of intermittent noise such as safety vents, pumps and compressors.

Designing a CHP installation often involves investigating the effects of the plant on the existing local noise profile. This should include surveying the existing noise levels at relevant points around the site and assessing how each part of the system contributes to the total noise.

Noise levels that damage health or are a nuisance are classified as 'statutory nuisances' under the Environmental Protection Act 1990. Local authorities have a duty to investigate any complaints.

3.2.1 Exhaust Noise

Engines and gas turbines frequently require a silencer in the ductwork or chimney to reduce the exhaust noise; this can sometimes be avoided by a waste heat recovery boiler attenuating the sound of the prime mover. Exhaust silencing may be required because of the chimney height, the type of engine or turbine, and the design of the waste heat recovery system or other factors. Typical exhaust noise profiles for gas turbines and reciprocating engines are illustrated in Table 12.

Table 12 Sound levels from CHP prime movers

Frequency (Hz)	125	250	500	1,000	2,000	4,000	8,000
Gas turbine (dB)	120	120	116	112	110	105	95
Reciprocating engine (dB)	125	126	120	112	100	92	82

In general, all prime movers give out more noise at lower frequencies, particularly in reciprocating engines. The noise level from gas turbines, however, is more even over different frequencies.

To meet local environmental requirements, exhaust silencer design for prime mover exhausts must consider the sound level profile. Silencers are available that reduce noise levels to 80 dB(A) at the chimney outlet. The exhaust silencer must reduce noise levels without creating an excessive pressure drop across the silencer, as this can effect the prime mover's performance and efficiency.

CHP systems frequently include an exhaust by-pass and chimney so that the prime mover can operate for short periods without any heat recovery. A silencer must be incorporated in the by-pass for noise levels at the stack exit to be acceptable.

3.2.2 Ambient Noise

An acoustic enclosure is usually put round the CHP prime mover to reduce the ambient noise. The CHP plant is normally in a building which has been specially designed to attenuate noise. Ventilation inlet and outlet ducts on the acoustic enclosure will probably require small silencers.

The CHP system always includes a range of auxiliary equipment such as fans, pumps and motors which may require sound attenuation. In particular, fuel or air compression systems require acoustic enclosures or buildings to suppress the noise they generate.

As reciprocating engines tend to make more noise than gas turbines at low frequencies, the design of the acoustic enclosure should take this into account. Foundations and engine mountings need to control engine vibrations, particularly from larger low-speed machines. Gas turbines do not vibrate as much, but the design of a turbine's combustion air intake requires acoustic control.

3.3 Visual Impact of Buildings and Structures

Installing CHP requires buildings for the prime mover, boiler, and auxiliary equipment such as pumps and compressors. These buildings are often built on the edge of an industrial site to be near to gas and electricity systems. The building design should consider the visual impact on the local area, particularly where buildings can be seen by the public.

Local authority planning requirements may restrict building design and require trees or other barriers to screen the site. The local authority planning departments should be able to advise on screening requirements. Early consultation with the local authority and other community organisations is essential to identify possible problem areas that may delay the project.

3.4 Disposing of Liquid Effluents

A CHP plant does not generate large quantities of liquid effluent. However, the following effluents can cause environmental damage if not controlled and should be considered in the system design.

- Boiler blowdown and drain effluent contain suspended solids and quantities of chemicals used for treating the boiler feedwater. The total water content of the boiler needs to be drained through the system for boiler maintenance and inspection purposes.
- Effluent from water treatment plant which arises from periodic washing and system re-generation.
- Effluent drainage from plant cleaning procedures such as turbine washing systems.
- Effluent generated by installation and commissioning procedures including pipework flushing and chemical equipment cleaning.

Disposing of any liquid effluent in a public sewerage system or into the environment requires approval from the appropriate authority. Some form of treatment may be required for these effluents and some sites have an existing suitable effluent treatment system. In some cases effluent will need to be put in containers, removed, and disposed of by specialist contractors.

3.5 Storing and Containing Materials

A range of environmentally damaging materials is used in the operation of a CHP plant and auxiliary equipment. During design and operation of the plant precautions must be taken to prevent accidental releases and this may mean incorporating detection and alarm systems.

A large number of design and engineering standards and codes of practice exist to improve safety and reduce risk to the environment of accidental leaks or spills of hazardous substances. Further information on sources of good engineering practice are listed in Appendix 2.

3.5.1 *Natural Gas*

All fittings and pipework must be designed, and installed, to meet specifications and regulations. The system must be specified and tested for soundness throughout its service life. In areas of risk, gas leakage detection is recommended, together with automatic supply shut-off in the event of a leakage.

3.5.2 *Storing and Containing Oils and Chemicals*

All liquid substances used in bulk by a CHP plant, such as fuels, lubricants and chemicals should be stored in tanks. All tanks should be located within catchment bunds big enough to contain any leakage. Unloading points for bulk delivery vehicles should be designed to contain any spillages in a safe area.

Equipment such as water treatment plant should be sited in a bunded area to contain spillages. A bunded area should also be available to store materials supplied in portable containers, with procedures and equipment for safe handling. It is advisable to incorporate a sump to surface drain the CHP plant area. This ensures all types of liquid can be disposed of safely.

3.5.3 *Handling and Storing Coal*

Coal must be delivered into a safe and secure storage area. It should be handled in such a way to minimise the creation of airborne dust and particles. It may be necessary to install water sprinklers to dampen down material prior to handling. Run-off water must be collected and treated to meet appropriate discharge requirements. Coal must be stored in a ventilated area to prevent a build-up of methane gas.

4. ENVIRONMENTAL LEGISLATION RELATING TO RELEASES FROM COMBUSTION PROCESSES

Although every effort has been made to ensure that the information contained in this Guide is accurate, the Department of the Environment, the Energy Efficiency Office and ETSU cannot accept liability for any errors, omissions or misleading statements in the information, whether caused by negligence or otherwise. Readers should refer to the relevant documents to verify actual requirements.

4.1 A Brief History of UK Legislation

The Alkali Act 1906 was the first significant step to legislate emissions into the atmosphere. Although limited in its application, the Act used the concept of Best Practicable Means (BPM) to 'prevent escapes of noxious or offensive gases' from a range of industrial processes. This concept remained part of a system of prior registration of works and was re-enforced by the Health and Safety at Work etc Act 1974. This Act also created the Health and Safety Executive with a wide brief, including control of emissions from industrial premises.

The Public Health Act of 1936 confirmed the concept of 'statutory nuisance' for control of 'dust or effluvia being prejudicial to health or being a nuisance to local inhabitants'. This Act also gave powers to local government bodies to make by-laws to control smoke emissions. The subsequent Clean Air Acts of 1956 and 1968 further limited smoke emissions and introduced the first formal method for assessing minimum heights of industrial chimneys according to the quantity of sulphurous emissions.

In 1976 the Royal Commission on Environmental Pollution established the objective of directing pollutants to the environmental medium where least damage would occur. This principle is recognised as the Best Practicable Environmental Option (BPEO). The Commission also identified the role of local authorities in pollution control. In 1986 a need for Integrated Pollution Control (IPC) was recognised as an effective way to ensure pollution problems had optimum solutions to maximise environmental benefits.

4.2 EC Legislation on Atmospheric Emissions

The European Community (EC) is committed to environmental protection as a central issue in its policies.

The EC Directive on Combating of Air Pollution from Industrial Plants was issued in 1984. This has become known as the 'framework' Directive as it identified areas of concern and introduced a system of authorisation. However, it did not limit emissions of specific pollutants. The Large Combustion Plant Directive of 1988 requires each Member State to implement a programme of action to reduce emissions of NO_x and SO₂. CHP plants and installations incorporating gas turbines and engines were excluded from the requirements. The Directive required each Member State to draw up a programme of objectives so that the required reduction is achieved by limiting emissions in new and existing plants.

The EC has also introduced directives on air quality which limit the concentrations of NO₂ and SO₂ found in ambient air at ground level.

4.3 UK Legislation Affecting Combustion Processes

Following the EC directives on air quality, the Air Quality Standards Regulations 1989 were issued in the UK. This gives the Department of the Environment (DoE) the power to ensure that the concentrations of certain airborne pollutants do not exceed specified limits. The limits defined by these regulations are used in new procedures to assess the required height of industrial chimneys and therefore apply to some CHP installations.

The Environmental Protection Act 1990 (EPA) is the main legislation controlling atmospheric emissions in the UK. This consolidated many of the powers of previous UK statutes and incorporates ways to comply with EC requirements, as well the Large Combustion Plant Directive in the UK. For each environmental medium, the EPA has defined 'prescribed' potentially harmful substances that need to be controlled to prevent, or minimise, discharge into the environment. The Act has also introduced the BATNEEC (Best Available Techniques Not Entailing Excessive Cost) principle as the criterion used to regulate the release of prescribed substances.

The first pollution control instigated by Part 1 involves operating IPC. This regulates the release of prescribed substances to air, land, and water. Processes coming under IPC control are referred to as 'Part A' processes. For larger schemes (>50 MWth input), this is enforced by Her Majesty's Inspectorate of Pollution (HMIP) in England and Wales and Her Majesty's Industrial Pollution Inspectorate for Scotland (HMIPI) in Scotland. In Northern Ireland pollution control is regulated by the Environment Service of the DoE, though the EPA does not apply.

CHP is regulated for IPC in the Combustion Processes section of the Fuel and Power group of prescribed processes. The main objectives of IPC are summarised as:

- to apply BATNEEC to minimise the release of pollutants and to render harmless any that are released;
- to consider discharges of pollutants into land, air, and water, in the context of minimising damage to the environment as a whole by achieving the BPEO;
- to monitor and enforce compliance with statutory requirements.

Under present jurisdiction, a CHP installation may be subject to IPC, depending on its overall size and the nature of its location. IPC is administered by issuing and revising an authorisation to operate every four years, or when a substantial change is made in the process. The application procedure requires:

- demonstration of the equipment and systems to achieve the objectives of IPC for those substances that are 'prescribed' for the process;
- assessment of the environmental consequences a release of any prescribed substances may have;
- procedures for monitoring the discharge of prescribed substances.

The application and authorisation are placed on public record.

HMIP have issued Guidance Notes for combustion processes covering gas turbines, compression ignition engines, and boilers. These documents give guidance on current and future limits of emissions concentrations, together with controls on the sulphur content of fuels and monitoring requirements. Any requirements for authorisation will be determined by HMIP, taking into account the need to achieve BATNEEC for the particular process.

A summary of emissions limits applicable to Part A CHP processes is given in Table 13 and the Guidance Notes are listed in Appendix 2.

Table 13 Summary of emissions limits from Part A Guidance Notes

	Gas turbines	Reciprocating engines	Boilers
NO_x			
Gas-firing	125 mg/m ³	650 mg/m ³ ⁽¹⁾	350 mg/m ³
Oil-firing	165 mg/m ³	1600 mg/m ³ ⁽²⁾	450 mg/m ³
Coal-firing			650 mg m ³
SO₂			
Gas-firing	max sulphur in fuel 70 mg/MJ	max sulphur in fuel 500 ppm by volume	5 mg/m ³
Oil-firing	max sulphur in gas-oil 0.3% by weight	max sulphur in heavy oil 2.0% by weight	1,700 mg/m ³
Coal-firing			2,200 mg/m ³

⁽¹⁾ 750 mg/m³ for existing engines, reducing to 650 mg/m³ in 1999.

⁽²⁾ 1,800 mg/m³ for existing engines, reducing to 1,600 mg/m³ in 1999.

Note: All ppm limits are volumetric, dry, at 273 K, 1,013 mbar, expressed at 15% O₂ for turbines and engines, at 3% O₂ for oil- and gas-fired boilers and 6% for coal-fired boilers.

Limits for supplementary firing in a waste heat boiler are calculated by averaging the prime mover and boiler NO_x limits in proportion to the fuel inputs.

Limits for hydrocarbons and CO apply to compression ignition engines.

Limits for particulates apply to boilers.

The second pollution control instigated by Part 1 of the EPA defines the duties of local authorities in regulating air pollution from 'Part B' processes. The Secretary of State has issued Guidance Notes on processes to be controlled by the environmental health department of the local authority. These include emissions limits and operating factors which must be considered by the local authority before granting authority to operate. Under the new Clean Air Act 1993 local authorities are also required to authorise chimney heights for smaller combustion processes and control 'statutory nuisances' covered by Part 3 of the EPA (20 - 50 MWth plant).

A summary of the emissions limits that apply to Part B CHP processes is given in Table 14 and the Guidance Notes are listed in Appendix 2.

Table 14 Summary of emissions limits from Part B Guidance Notes

	Gas turbines	Reciprocating engines	Boilers
NO_x ⁽¹⁾			
Gas-firing	60 ppm	660 ppm ⁽²⁾	200 mg/m ³
Oil-firing	90 ppm	660 ppm ⁽²⁾	300 - 600 mg/m ³
Coal-firing			500 - 650 mg/m ³
SO₂			
Gas-firing	max sulphur in fuel 70 mg/MJ		35 mg/m ³
Oil-firing	max sulphur in fuel 0.3% by weight	max sulphur in fuel 2.0% by weight	3,000 mg/m ³
Coal-firing			3,000 mg/m ³ ⁽³⁾

⁽¹⁾ NO_x limits for gas turbines and engines are based on net efficiencies of 27.5% and 40% respectively. The applied limit is adjusted in accordance with actual prime mover efficiency.

⁽²⁾ Reduces to 500 ppm on 1/10/96, and to 360 ppm on 1/10/99.

⁽³⁾ Reduces to 2,000 mg/m³ for non-indigenous coal.

Note: All ppm limits are volumetric, dry, at 273 K, 1,013 mbar, expressed at 15% O₂ for turbines and engines, 3% O₂ for oil- and gas-fired boilers and 6% O₂ for coal-fired boilers.

Limits for supplementary firing in a waste heat boiler are calculated by averaging the prime mover and boiler NO_x limits in proportion to the fuel inputs.

Limits for new plant generally apply from date of operation; implementation dates for limits applied to existing plant vary.

Limits for particulates apply to boilers.

4.4 Pollution Control for CHP Installations

A CHP plant is subject to EPA control according to the energy input rating of the individual items of plant as there are no Guidance Notes specific to CHP installations.

A CHP plant that recovers heat from a prime mover is covered by requirements relating to the prime mover. A CHP plant that burns fuel in a boiler is required to comply with the standards for boiler plant, irrespective of whether the boiler also recovers prime mover heat. Consequently, the design and the heat input capacity of a CHP scheme will determine the legislative environmental requirements that must be met.

In order to determine which pollution control regime applies to a CHP plant, consider two simple questions and answers about the design capabilities of the CHP plant.

- 1 Does the total maximum fuel burning capability of **either** all the prime movers **or** all the boilers that form the CHP plant exceed 50 MW (on a net calorific value basis)?
If yes, the installation will be covered by IPC, and HMIP authorisation will be required for a Part A process. If not, then proceed to next question.
- 2 Does any **individual** item of equipment within the CHP plant have the capability to burn fuel at a rate exceeding 20 MW (on a net calorific value basis)?
If yes, then that item of equipment will be subject to Local Authority Air Pollution Control as a Part B process. If not, then proceed to next point.
- 3 Although no authorisation is required under the EPA, chimney height must be authorised by the local authority under the Clean Air Act 1993.

After deciding which pollution controls apply to the plant, consult the local authority and use a guidance note to work out how to comply with the environmental legislation. The local authority or HMIP can help with any queries. A list of contact addresses is given in Appendix 6.

CHP prime movers and boilers can be designed and operated to meet emissions limits using proven techniques and without excessive capital and operating costs. Regulatory authorities do not aim to make CHP uneconomic or unviable and CHP emission savings should be regarded as a significant factor in assessing emissions controls.

4.5 Future Environmental CHP Legislation

The objectives of the EPA are expected to stay the same for the foreseeable future. However, the possibility of a new Environmental Protection Agency may result in the legislation being technically restructured. The pollution control constraints and procedures will be reviewed at periodic intervals. The DoE have indicated that all guidance notes will be reviewed every four years or less. These revisions will need to take into account any future legislation as well as technical developments that come under BATNEEC.

An example of this procedure is the recent consultation draft of a revision to the guidance note for gas turbines. This proposes to lower the permitted levels of NO_x emissions for some gas turbines to reflect the latest techniques. However, reviews of guidance notes will not automatically result in requirements being tightened when authorisations renewals arise. BATNEEC recognises it must not burden CHP users with excessive costs.

The environmental directorate of the Commission of the European Community is expected to be another driving force on environmental legislation. An initial consultation, on the draft of a directive on emissions from gas turbines, is likely to result in emissions limits being applied to gas turbines smaller than those currently covered by UK guidance notes. There is also an intention to introduce a directive to control emissions from the smaller industrial and commercial boilers not already covered by the Large Combustion Plant Directive.

5. ENGINEERING DESIGN TO MINIMISE EMISSIONS

5.1 Suppressing NO_x Formation

Techniques and systems are available to limit the production of NO_x in combustion systems. The main technique for lowering NO_x production in a combustion process is to reduce the average temperature within the combustion zone.

5.1.1 Gas Turbines

Injecting water or steam into the turbine combustion chamber reduces NO_x by lowering the average combustion temperature (see Fig 5). Typically 50% to 100% of the fuel input rate must be injected. This also slightly increases turbine output and very slightly decreases CHP system efficiency.

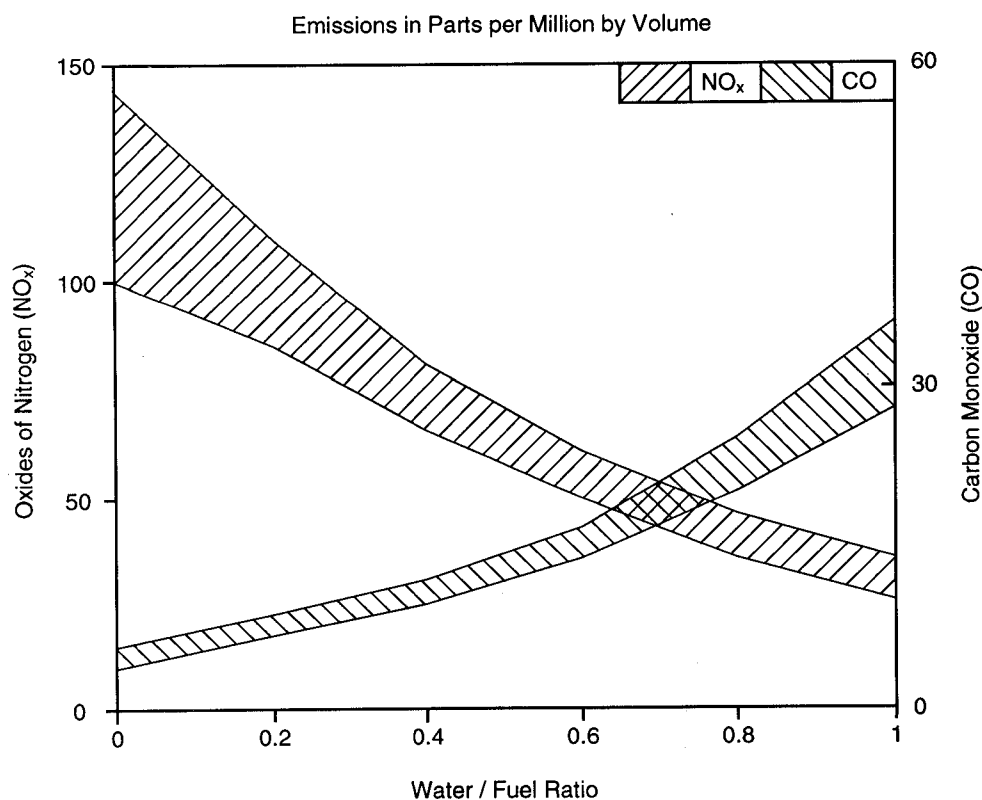


Fig 5 NO_x and CO emissions from gas turbines with water injection

To avoid damage to the turbine, high purity water or steam must be injected. Even so injection tends to reduce the life of some of the turbine components and has operating cost implications for the turbine and associated systems. Gas and gas-oil firing systems can use injection and virtually all gas turbines can be fitted with either water or steam injection. As levels of water or steam are raised, CO level in the exhaust rises due to partial quenching of the flame (see Fig 5).

The equipment needed to treat and inject water or steam into a gas turbine increases capital costs of a CHP scheme by around 2% to 3%. Operating costs are typically increased by less than 1%.

Low- NO_x burners have been developed for most large gas turbines and are now available for some smaller turbines. The burners are designed to operate with a lower temperature flame to reduce NO_x emissions. At present, these burners can burn only gaseous fuels in low- NO_x mode and some have no capability to burn gas-oil at all. Low- NO_x burners in UK CHP plants are not available for most smaller turbines and are limited by a requirement for dual fuel capability due to the predominance of interruptible gas tariffs.

Current research is aimed at incorporating catalysts into turbine combustion systems. This has yet to establish the feasibility, durability and cost-effectiveness of catalytic control of NO_x emissions in gas turbines.

All gas turbines can be installed and operated to comply with the emissions limits currently required by pollution control legislation.

5.1.2 *Compression-ignition Engines*

The current technique used to reduce NO_x emissions from these engines involves adjusting the design and operation of the engine. An engine can be set up to give maximum power output, maximum energy efficiency, or for minimum NO_x emissions. All configurations vary according to factors such as valve and injector timing, compression ratio, cylinder pressure, and intercooling. An engine configured for minimum NO_x emissions will not operate at maximum efficiency. This results in a marginal increase in the CO_2 emissions from the engine. Another technique to achieve lower NO_x in CI engines is to use a relatively high level of excess air in the combustion chamber resulting in lower average combustion temperatures.

Several control techniques are being researched to achieve lower NO_x outputs although none of these has yet proved feasible or cost-effective in long term operation. These include:

- emulsification of water in liquid fuels;
- water spray in combustion air intake;
- partial re-circulation of cooled exhaust gases into the combustion air.

At present, most CHP schemes based on CI engines fall below the threshold of pollution control under IPC. Appendix 7 contains information on spark-ignition gas engine emissions reduction techniques.

5.1.3 *Boilers*

Recent developments in burner design give more accurate combustion control to reduce average temperatures and lower NO_x levels.

For CHP plants, the supplementary firing burner (see Good Practice Guide No 43) has the benefit of lower oxygen content in the combustion zone and of higher combustion efficiency. This results in lower NO_x emissions per unit of energy available. A CHP installation with supplementary firing can, with the correct design and operation, achieve the required emissions limits under all operating conditions.

5.2 *Treatment of Emissions in Exhaust Gas Streams*

A number of techniques for exhaust gas treatment have been developed in recent years to reduce the concentration of specific emissions produced in combustion processes. All techniques have been proven in service before being made widely available, but commonly add to the operating costs of a CHP plant and reduce efficiency by using additional energy. Producing feedstock materials also consumes energy. These techniques have generally only been used where it is necessary to comply with specific legislative or air quality requirements, and their application is not anticipated to grow in the UK.

5.2.1 *Selective Catalytic Reduction (SCR)*

SCR is a proven technique for reducing the NO_x in an exhaust stream by up to 90%. The process has been widely used in America and Japan, but has not been applied to CHP or power generation plant in the UK.

The technique involves blending ammonia (NH_3) in the exhaust stream and passing the mixture through a catalyst, where NO_x and NH_3 are converted to nitrogen and water. The catalytic reduction occurs at an exhaust temperature of around 300°C to 400°C . This is a disadvantage in a CHP application as it may require a more complex system design if prime movers have high exhaust temperatures. The SCR system control must minimise excess NH_3 remaining in the exhaust after the conversion process, particularly in exhaust from a fuel containing sulphur.

At present, application of SCR to CHP installations is only envisaged in special circumstances such as areas of high background NO_x levels. The overall cost of installation and operation of SCR would be prohibitive to almost all CHP installations in the UK.

5.2.2 *Non-catalytic Reduction*

Non-catalytic reduction has been applied in some boiler plant to reduce NO_x by up to 70%. Ammonia or urea is added in the combustion zone to convert NO_x to nitrogen and water. The technique has, however, proved difficult to apply in practice, as it requires a temperature range of between 900°C and $1,000^\circ\text{C}$ in the combustion zone in order to be successful. Under normal operating conditions, the temperature in the combustion zone of most boilers will vary outside this range.

5.2.3 *Flue Gas De-sulphurisation (FGD)*

Various proven techniques for the removal of SO_2 from exhaust gases are used in a number of countries world-wide. FGD is already installed and operating at some large coal-fired power stations in the UK as part of the flue gas treatment programme required by the EC Directive on Large Combustion Plant.

The wet technique consists of an absorption zone in which a mixture of water and ground limestone (CaCO_3) is sprayed into the exhaust gases. A series of chemical reactions takes place where the limestone slurry absorbs SO_2 from the exhaust. This is then passed into an oxidation zone where gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is produced as a by-product. The gypsum may be used in the building industry as a substitute for similar material from mining or quarrying. However, there is a limit to the amount of gypsum that can be used and it therefore may need to be disposed of as waste material. The efficiency of SO_2 removal can be as high as 90%. Using wet FGD to achieve high reductions in SO_2 contents is usually only practicable or cost effective for large scale applications (such as central power stations).

Dry sorbent de-sulphurisation systems, injecting powdered limestone or hydrated lime, are fitted to a few UK combustion processes. These can achieve worthwhile SO_2 reductions using bag filters to collect solid gypsum waste in the exhaust systems. Similar systems have been developed using sodium bi-carbonate powder. Dry sorbent systems are one of the cheaper sulphur abatement techniques for industrial size CHP plants and can achieve up to 75% removal efficiency. Nevertheless, the installation and operating cost will have a significant effect on the viability of the operation. In many cases, it will be preferable to use fuels with lower sulphur contents.

6. THE WAY FORWARD

There is an increasing commitment to the growth of CHP on both economic and environmental grounds and a more stable climate for investing in energy efficiency. Assessing CHP viability (as discussed in Good Practice Guide No 43) should, therefore, include a quantitative assessment of the reductions in emissions that CHP can achieve. Growing environmental regulation will encourage more efficient use of primary fuels and energy, and replacement of older equipment and techniques.

In assessing the viability of a CHP scheme, approaching the local authority planning and environmental departments early should give an indication of the potential environmental sensitivity of the scheme. In particular, the design aspects required to meet air quality targets and to meet other local requirements, can be assessed. It may be appropriate at this stage to prepare a brief initial statement defining the extent of the scheme and assessing its environmental effects. This can be published early on for consultation with local interest groups.

Once the size and type of the scheme has been defined, if appropriate, it is important to discuss the proposals with the regulatory authority. This should confirm which pollution control authority will regulate the operation of the CHP scheme and give firm guidance on the environmental performance conditions that will be applied.

Note: If the CHP scheme will have a fuel input of 50MW or more, contact HMIP.

If the CHP scheme will have a fuel input of 20 - 50 MW, contact the Local Authority pollution unit.

If the CHP scheme will have a fuel input below 20 MW, refer to the Clean Air Act 1993 requirements and contact the Local Authority.

APPENDIX 1

TABLES OF DATA AND CONVERSION FORMULAE

Atomic and molecular weights relating to combustion processes

carbon	C	12
nitrogen	N ₂	28
carbon monoxide	CO	28
oxygen	O ₂	32
sulphur	S	32
carbon dioxide	CO ₂	44
nitrogen dioxide	NO ₂	46
sulphur dioxide	SO ₂	64

Conversion Formulae for Emissions Concentrations

Emissions are expressed in various units as follows:

ppm *parts per million of emissions by volume*

mg/m³ *milligrams of emissions per cubic metre*

Both of the above units must be related to reference conditions, which are usually 0°C, dry, 1,013 mbar. Also, the measurement is usually 'normalised' to a defined percentage oxygen content in order to obtain comparability of readings.

mg/MJ (g/GJ) *milligrams per unit of net thermal input to the combustion process*

This unit of measurement is independent of temperature, pressure and other exhaust constituents.

Conversion between these units can be achieved by use of the following formulae and the molecular weight (MW) of the emissions being measured:

$$a) \quad \text{mg/m}^3 = \frac{\text{ppm} \times \text{MW}}{22.4}$$

$$b) \quad \text{ppm (at } x\% \text{ O}_2) = \frac{\text{ppm (at } y\% \text{ O}_2) \times (20.9 - x)}{(20.9 - y)}$$

c) for NO_x (NO₂) only:

$$\text{ppm (at } x\% \text{ O}_2) = \frac{a}{21 - x} \text{ mg/MJ}$$

where: $a = 11.1$ for coal or oil fuel

$a = 10.3$ for natural gas fuel

APPENDIX 2**BIBLIOGRAPHY AND RELATED DOCUMENTATION**

HMIP Chief Inspector's Guidance to Inspectors:

- Process Guidance Note IPR1/1 Combustion processes: large boilers and furnaces
50 MWt and over
- Process Guidance Note IPR1/2 Combustion processes: gas turbines
- Process Guidance Note IPR1/3 Compression ignition engines 50 MWt and over

Secretary of State's Guidance Notes:

- PG1/4(91) Gas turbines, 20-50 MW net rated thermal input
- PG1/3(91) Boilers and furnaces, 20-50 MW net rated thermal input
- PG1/5(91) Compression ignition engines, 20-50 MW net rated thermal input

HMIP Technical Guidance Note (Dispersion) D1, Guidelines on Discharge Stack Heights for Polluting Emissions

Chimney Heights, Third edition of the 1956 Clean Air Act Memorandum

Survey of Nitrogen Oxides, Carbon Monoxide and Hydrocarbon Emissions from Industrial and Commercial Boilers in Scotland, WSL Report LR 524.

Good Practice Guide No 43, 'Introduction to Large-Scale Combined Heat and Power'

Good Practice Guide No 115, 'An Environmental Guide to Small-Scale Combined Heat and Power'

APPENDIX 3**SOURCES OF FURTHER INFORMATION**

Energy Efficiency Enquiries Bureau
ETSU
Harwell
Oxfordshire
OX11 0RA
Tel: 0235 436747/432735

Combined Heat and Power Association
Third Floor, Grosvenor Gardens House
35/37 Grosvenor Gardens
London
SW1W 0BS
Tel: 071 828 4077

Institution of Environmental Health Officers
Chadwick House
Rushworth Street
London
SE1 0QT
Tel: 071 928 6006

AEA Technology
National Environmental Technology Centre
Culham
Abingdon
Oxon
OX14 3DB
Tel: 0235 463040

APPENDIX 4**ENERGY CONVERSION TABLES****SI Units**

The SI (Système Internationale) unit of energy is the joule. Large quantities are expressed as multiples indicated by the following prefixes.

Factor	Prefix	Symbol
10^3	kilo	k
10^6	mega	M
10^9	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E

Conversion factors for energy units

	Btu	joule	kWh	therm
Btu	1	1.055×10^3	0.2931×10^{-3}	10×10^{-6}
joule	0.948×10^{-3}	1	0.2778×10^{-6}	9.48×10^{-9}
kWh	3.412×10^3	3.6×10^6	1	34.12×10^{-3}
therm	100×10^3	105.5×10^6	29.31	1

Heat supplied basis energy values of fuels

	Heat supplied basis*
Fuel oil	185 MJ/gallon 40.8 MJ/litre 43.3 MJ/kg 43.3 GJ/tonne
Electricity	3.6 MJ/kWh
Natural gas	38.6 MJ/Nm ³
Derv	177 MJ/gallon
Other liquid fuels	189 MJ/gallon
Tonne coal equivalent**	26.5 GJ/tonne

* The heat supplied energy value is energy a fuel is capable of providing at the point of use. The primary fuel equivalent takes into account losses incurred in refining fuels, or converting them to familiar forms and losses in distribution.

** The tonne coal equivalent is a unit defined for statistical purposes in the UK as 250 therms (1978) which is different from international convention.

Other conversion factors

1 ton	=	1.016 tonne
1 lb	=	0.4536 kg
1 gallon	=	4.546 litres

APPENDIX 5**EMISSIONS FROM CENTRAL POWER GENERATING STATIONS**

	Case 1	Case 2	Case 3	Case 4	Case 5
	Coal-fired	Coal-fired (low NO_x)	Gas-fired combined cycle gas turbine	UK supply average coal-fired	UK supply average all sources
Emissions/unit of power provided					
CO ₂	990	990	450	990	684
NO _x	3.6	2.1	0.4 (dry low NO _x combustion)	2.7	1.7
SO ₂	15.0	15.0 (1.1 for FGD)	nil	15.0	9.0

Notes: All data in grammes of emissions per kWh of electrical power supplied.

Data include an allowance for losses in distribution system.

APPENDIX 6**CONTACT ADDRESSES FOR POLLUTION CONTROL AUTHORITIES**

Her Majesty's Inspectorate of Pollution
The Department of the Environment
Romney House
43 Marsham Street
London
SW1P 3PY
Tel: 071 276 0900

Her Majesty's Inspectorate of Pollution, East Division
Howard House
40-60 St John's Street,
Bedford
MK42 0DL
Tel: 0234 272112

Her Majesty's Inspectorate of Pollution, West Division
Highwood Pavilion
Jupiter Road
Patchway
Bristol
BS12 5SN
Tel: 0272 794653

Her Majesty's Inspectorate of Pollution, North Division
Stockdale House
Headingley Business Park
Victoria Road
Headingley
Leeds
LS6 1PF
Tel: 0532 786636

Air Quality Division, Local Authority Unit
Department of the Environment
Wrens Court
Lower Queen Street
Sutton Coldfield
B72 1RT
Tel: 021 362 1077

Her Majesty's Industrial Pollution Inspectorate
The Scottish Office Environment Department
27 Perth Street
Edinburgh
EH3 5RB
Tel: 031 244 3062

Environment Service
The Department of the Environment, Northern Ireland
Calvert House
23 Castle Place
Belfast
BT1 1FY
Tel: 0232 230560

APPENDIX 7

NEW GAS ENGINE DEVELOPMENTS TO MINIMISE EMISSIONS

In a gas engine, the amounts of NO_x , CO and unburnt hydrocarbons (UHC) in the exhaust are influenced by the quantity of air mixed with the fuel in the engine; natural gas needs around 17 parts of air to burn one part of gas. The graph in Fig 6 shows how the amounts of emissions varies if more or less air is mixed with the fuel.

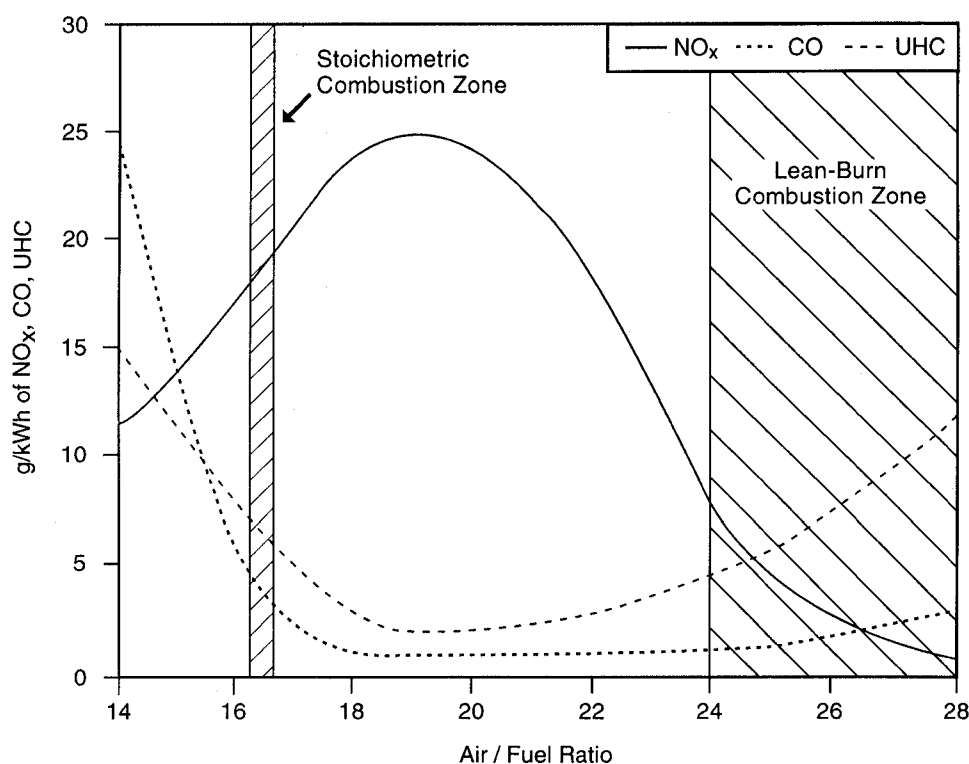


Fig 6 Variation of emissions with air mix in fuel

If the mixture contains exactly enough air to burn the fuel, then this is called 'stoichiometric' combustion and the exhaust has no oxygen in it. This enables a special catalytic converter to be added to the exhaust system; this is known as a '3-way catalyst' as it converts NO_x , CO and UHC into water, CO_2 and nitrogen, giving a much cleaner and less harmful exhaust.

Another recent development is a 'lean burn' engine, which runs with a high air content, typically around 50% excess air. These engines produce low levels of NO_x , but emissions of unburnt fuel are higher and an 'oxidation' catalyst can be used to convert this unburnt fuel into CO_2 and water.

In order for these new engine types to succeed in giving cleaner exhausts and lower emissions, catalytic converters have now been developed that are reliable, affordable and long-lived. A comparison between the types of engine is shown as follows.

Stoichiometric engine	Lean-burn engine
Accurate air/fuel control is needed to apply a 3-way catalytic converter	Air/fuel mixing using standard equipment giving stable air/fuel ratio
Higher electrical output for same size of engine	Higher thermal efficiency giving lower emissions of CO ₂
Higher temperatures giving increased wear and higher maintenance costs	Lower cylinder temperatures give longer component life and lower maintenance costs
Increased oil deterioration due to higher nitration rates	Longer oil and spark plug life
Higher NO _x output if catalyst is not used	Higher unburnt fuel output if catalyst is not used.
	Risk of combustion instability if air/fuel ratio is too high

For further copies of this or other Best Practice programme publications please contact BRECSU or ETSU.

For buildings-related projects: Enquiries Bureau, BRECSU, Building Research Establishment, Garston, Watford WD2 7JR.
Tel No: 0923 664258. Fax No: 0923 664787.

For industrial projects: Energy Efficiency Enquiries Bureau, ETSU, Harwell, Oxfordshire OX11 0RA.
Tel No: 0235 436747. Fax No: 0235 432923. Telex: 83135.